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Running head: Neural Correlates of Spatial Location Mapping on the Simon Effect in Mandarin Speakers

Neural Correlates of Spatial Location Mapping on the Simon Effect in Mandarin Speakers

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Abstract

The aim of study is to investigate the neural mechanisms by which experience influences cognitive control in native Mandarin speakers using functional Magnetic Resonance Imaging (fMRI) in a Simon location task. Results showed brain regions involved in motor control (precentral and postcentral gyri) were less activated after practice. In contrast, brain regions involved in selection of conflict response (left inferior frontal gyrus), attentional control (inferior parietal lobule) and working memory (inferior frontal gyrus, superior temporal gyrus and insula lobe) were more activated after practice. The results suggest that learning an incompatible spatial location mapping during practice increased demand for response inhibition. Furthermore, the data reveal the involvement of verbal working memory during motor learning in the Simon spatial location mapping task in Chinese speakers.

Keywords: Simon effect, functional Magnetic Resonance Imaging, working memory, motor learning

Neural Correlates of Spatial Location Mapping on the Simon Effect in Mandarin Speakers

Cognitive control is the uniquely human ability to direct our thoughts and actions based on intentions. This ability is central to many higher cognitive functions, such as language, reasoning, planning and problem solving (Botvinick, Braver, Barch, Carter & Cohen, 2001; Miller & Cohen, 2001). Cognitive control is also related to how we process information and how the processing of information changes with experience (e.g., practice). The latter question is of interest in the study of human performance and for understanding cognitive mechanisms necessary for rehabilitation after brain damage.

Choice-reaction tasks are numerous in experimental psychology. In such tasks, participants are required to respond as quickly and accurately as possible to a stimulus with an assigned key press (button response) (Proctor & Lu, 1999). Simon task is one of such choice-reaction tasks widely used to study the relationships between task practice and performance (e.g. Lu & Proctor, 1995; Proctor, Yamaguchi, Zhang & Vu, 2009). Simon effect refers to the finding that it takes less time to respond to a target when the spatial location of the stimulus corresponds to the location of response (i.e. compatible condition) than when the stimulus does not correspond to the location of a response (i.e., incompatible condition). This effect is observed even if the location is not related to stimulus dimension (e.g., colour) (Nicoletti, Anzola, Rizzolatti & Umiltà, 1980). Dual-route cognitive models are the most widely accepted accounts for the Simon effect (Wuhr & Ansorge 2007). Such models assume two independent routes through which stimuli may activate responses, the controlled route and the automatic route. The controlled route is believed to depend on short-term associations, established in working memory (WM), on the basis of task instructions. The relevant

stimuli feature (e.g. colour) activates an arbitrary response to that feature through the controlled route. On the other hand, the automatic route is assumed to depend on long-term associations. The spatial position of a stimulus activates a spatial corresponding response through the automatic route. If the two routes activate the same response (compatible condition), there is no conflict in performance. However, if the two associations activate different responses, there is an increase in reaction time because the Short-term memory (STM) association makes response selection slower due to conflict i.e. the Simon effect. In addition, STM or WM is assumed to be independent to the coding of spatial location in the Simon task in this model (Zhang, Zhang & Kornblum, 1990). In contrast to the dual-route model, Ansorge and Whur (2004) proposed that the codes represented in WM used to discriminate alternative response can influence the Simon effect. Similarly, Vu (2007) suggested the WM may contribute to the Simon effect.

Studies investigating the neural correlates of the Simon effect (Maclin, Gratton & Fabiani, 2001; Peterson et al., 2002; Fan, Flombaum, McCanniss, Thomas & Posner, 2003; Liu, Banish, Jacobson & Tanabe, 2004) reveal a fronto-parietal network is involved in the Simon effect. In the study of Fan et al., three tasks involving a cognitive conflict (colour word Stroop task, flanker task and spatial conflict task) were performed and fMRI was used to identify brain activations during task performance. Two common brain areas involved in conflict detection on the three tasks are the anterior cingulate cortex (ACC) and the left prefrontal cortex. Fan showed that the ACC, dorsolateral prefrontal cortex (DLPFC) and pre-supplementary motor area were both significantly activated in the incompatible condition relative to the compatible condition. These findings support the view that the ACC is responsible for monitoring conflict and response errors, while the DLPFC receives signals from

ACC and then modulates the processing in the posterior parietal cortex via biasing towards the task-relevant information (e.g. Botvinick et al., 2001).

A remarkable feature of the Simon effect is that it can be modulated by practice. Previous studies have shown that performing incompatible spatial location mapping tasks can eliminate the benefit for spatial correspondence in a subsequent Simon task (e.g. Dutta & Proctor 1992; Proctor & Lu, 1999; Fan et al. 2003; Proctor et al. 2009). Proctor et al. (2009) showed the Simon effect can be eliminated after 84 trials following practice with an incompatible mapping of left-right locations with a key press prior to the Simon task, or even reversed with more practice trials (i.e., faster response in incompatible conditions). They suggested the practice effect of incompatible spatial location mapping on subsequent Simon task is due to the formation of short-term-memory associations in WM defined for the spatial task remaining active in the subsequent Simon task according the dual route theory.

There is no brain imaging research into the neural mechanisms underlying the influences of incompatible spatial location mapping on the Simon effect. Therefore, the aim of the present study is to investigate this question using fMRI. Based on prior studies of practice on the Simon effect, participants will be given two identical Simon tasks manipulating physical-location stimuli. A spatial location mapping task will be performed between the two Simon tasks. One Simon Task will serve as a control baseline, while another will serve as a transfer task to assess the effect of spatial location mapping. To measure the brain correlates of practice on the tasks, effective connectivity within a brain network that is involved in the Simon effect will be assessed via dynamic casual modeling (DCM) (Friston, Harrison & Penny, 2003). This method of fMRI data analysis will allow a comparison between brain activation observed in the control and transfer sessions. To test the dual route account of practice

in the Simon effect whereby the effect of practice is assumed to result from short-term-memory stimulus-response (S-R) associations that depend on comprehension of task instructions, individual differences in working-memory capacity will be correlated to the magnitude of practice effect to test predicted relationships between the variables.

No study has examined the effect of practice on the Simon effect in Chinese speakers. Indeed, all previous research was performed with native English speakers. Although this is not surprising, it does limit the theoretical implications of previous studies as it is not yet known whether the effects of practice on the Simon effect are culturally determined. One reason to assume that there may be a cultural effect of practice on the Simon effect is the finding that adult bilingual speakers are less likely to produce a standard Simon effect than monolingual speakers (Bialystok, Craik, Klein & Viswanathan, 2004). One explanation for this finding is that bilingual speakers are required to monitor and to switch between languages more frequently and thus they develop greater cognitive control for a variety of skills. As language experience has an effect on performance in the Simon task, it is possible that cultural differences may emerge. It is therefore a valid question to ask if native Chinese speakers demonstrate a Simon effect and whether there is an effect of practice on reducing the Simon effect in such individuals.

The primary hypothesis is: if reduced Simon effect is due to short-term-memory associations defined for the spatial task remaining active in a subsequent Simon task, then the brain regions known to be involved in working memory tasks should be more active in the transfer sessions (following practice) than in the control sessions. In addition, it is expected that if short-term-memory associations explain the reduction in Simon effect, participants who achieve better scores in a working memory task will

demonstrate a greater reduction in the Simon effect. Indeed such individuals may show a reversal in the Simon effect whereby spatially congruent trials are slower than spatially incongruent trials after practice and transfer sessions (Proctor et al., 2009). The second hypothesis is that after a block of practice with the incompatible spatial location mapping, conflict may be present for congruent trials as the short-term-memory associations established in the incompatible spatial mapping task should interfere with the spatial codes of stimuli in a subsequent Simon task. A specific prediction that can be derived from this hypothesis is that the anterior cingulate cortex (ACC), prefrontal cortex, dorsolateral prefrontal cortex (DLPFC) and pre-supplementary motor area will activate more in the congruent trials compared to the incongruent trials in the transfer task based on previous studies (e.g. Botvinick et al. 1999; Botvinick et al 2001).

Method

Participants.

Twenty right-handed participants aged between 20 and 35 (11 women and 9 men) were recruited from the University of Hong Kong. All participants were reported to have normal visual acuity and no history of neurological diseases or neuro-developmental delay. The participants were similar in educational and language background, each having at least 10 years of education.

Stimuli, procedures and method.

Language background questionnaire. The purpose of this questionnaire is to select native Mandarin speakers who are functionally monolingual. Participants were asked to fill in a language questionnaire online (appendix B). The language form addressed the percentage usage of first and second languages the participants use at home, school, with friends and for leisure activities. Participants with Mandarin as their first

language who are using Mandarin to communicate for more than 70% of the normal day were then recruited.

Working memory test. The effect of practice on the transfer session is assumed to result from short-term stimulus-response associations (Tagliabue, Zorzi, Umiltà & Bassignani, 2000). Hence, working memory was assessed to investigate the effect of individual differences in short-term memory capacity on the results. A modified operation-word span task (OSPAN) similar to that in the study of Kane, Bleckley, Conway and Engle (2001) was performed. Participants had to remember a list of unrelated words while solving a series of simple mathematical operations. One operation-word string was presented on screen at one time, with each set of strings ranging from two to six items in length. For example, a set of two strings here,

IS $(5 \times 2) - 8 = 2$? 車

IS $7 - (10/2) = 4$? 跳舞

Participants were instructed to read the operation-word pair aloud and respond using a key press whether or not the equation was correct. They were then asked to read aloud the word again. The next operation then appeared immediately. These steps were repeated, until visual cues appeared on screen to cue the participants to recall all of the words from that set only. Participants were instructed to write words in the order in which words had been presented. If participants failed to recall the words, they could make a cross to indicate the missing words. The only thing they could not do was to write the last word first. The OSPAN score was the sum of recalled words recalled in correct order. There were 15 trials for each participant in the test, in which there were three sets of each string length (from 2 to 6 operation-word pairs). Two practice trials were given. Different set sizes presented in a randomized order.

Questionnaire of Handedness. The Edinburgh Handedness Inventory (Oldfield ,

1971 was used to test participants' handedness to ensure all the recruited participants were right-handed (appendix C).

fMRI experiment: fMRI data were collected in the 3T MRI Unit of The University of Hong Kong. All MRI images were acquired with a Philips Achieva 3-T scanner (Best, Netherlands). A gradient echo planar imaging (EPI) sequence was used to acquire fMRI data with the following parameters: repetition time (TR) = 2,000 ms, echo time (TE) = 30 ms, field of view (FOV) = 240 mm, 32 axial slices, slice thickness = 3.0 mm, slice gap = 0.75 mm, in-plane resolution = $3.0 \times 3.0 \text{ mm}^2$, and flip angle = 90° . The first 4 volumes were discarded to allow for T1 equilibration effects. Additional high-resolution anatomical images (voxel size = $1 \times 1 \times 1 \text{ mm}^3$) were acquired using a standard T1-weighted 3-D Magnetization-Prepared Rapid Gradient-Echo (MP-RAGE) sequence.

Participants were divided into two groups: (1) the experimental group and (2) the control group. Each group consisted of 10 participants. All participants were assessed using fMRI for three sessions; (1) control, (2) practice and (3) transfer sessions. In the control and transfer sessions, participants performed two-choice color (red and green) discrimination tasks. Each trial began with a fixation cross (+) at the centre of the screen. Participants were instructed to look at the cross before a colored dot appeared. Stimuli were presented on either left or right side of the cross. Participants were asked to respond to one color with left key and another color with right key as fast and as accurately as possible. The assignment of stimuli color to the left and right response was counterbalanced across subjects (i.e. half of the participants in each group were asked to press left key for green color and the other half were asked to press left key for red color), with the condition that the same assignment was used for a given participant in both control and transfer sessions. This was done to avoid any

correlation between the color of the response key and its location. Stimuli remained on screen for 1000ms or until the participant's response. Two hundred and forty trials were presented in each session, half of which were congruent trials (stimuli presented on the same side as response key) and half of which were incongruent trials (stimuli presented on the opposite side to the response key), in a randomized order. In the practice session, a spatial mapping task was performed using non-colored (white) stimuli. For the experimental group, an incompatible spatial mapping task was performed. Participants were asked to press the left button when stimuli appeared on the right side of the screen i.e., the opposite side and vice versa. For the control group, a compatible spatial mapping task was performed. Participants were asked to press the left button when the stimuli appeared on the left side of the screen and vice versa. Three hundred trials were presented, as this number is required to show a reduced or reversed Simon effect for the incompatible mapping set (Lu & Proctor, 1995; Proctor et al., 2009). To make sure participants understood the instructions, 20 practice trials were given before each control and transfer session. Sixteen practice trials were given before the practice session.

Results

Imaging Data

Images were analyzed using Statistical Parametric Mapping (SPM8) software (Wellcome Trust Centre for Neuroimaging, University College London, London). EPI volumes were first corrected for head movements by affine registration. After realignment, a high-resolution T1-weighted image of the respective subject was co-registered to the mean realigned image. The co-registered T1-weighted image was spatially normalized to the Montreal Neurological Institute (MNI) template using the unified segmentation approach (Ashburner & Friston, 2005). The resulting

deformation parameters were then applied to the individual EPI volumes. All images were thereby transformed into standard stereotaxic space and re-sampled at $2 \times 2 \times 2$ mm³ voxel size. The normalized images were smoothed using an 8 mm full-width at half-maximum (FWHM) isotropic Gaussian kernel to compensate for residual variability after spatial normalization across subjects.

For the first-level individual statistical analysis, the fMRI blood-oxygen-level dependent (BOLD) data were analyzed in the framework of a general linear model (GLM). Each experimental condition was time-locked to the onset of the target color stimulus and was modelled using delta functions convolved with a canonical hemodynamic response function (HRF) and its temporal and dispersion derivatives (Friston et al., 1998). Low-frequency signal drifts were high-pass filtered using a cut-off period of 128 s. Temporal autocorrelation of fMRI volumes was modeled using an AR(1) process. The head movement estimates from the realignment procedure were entered as covariates to remove movement-related variance from the EPI time series. The following experimental conditions were modelled in SPM design matrix: (1) congruent and (2) incongruent conditions in the control session, (3) congruent and (4) incongruent conditions in the transfer session. In addition, the (5) left and (6) right stimuli in the practice session were also modeled, respectively, in the design matrix. For each subject, six contrast images were created for each experimental condition (each trial type versus baseline) and entered into the subsequent group analysis.

For the second-level random-effects analysis, the parameter estimates of BOLD response derived from the first-level analysis were entered into a fully factorial ANOVA with the factors group (experimental and control groups), session (control and transfer sessions), and congruency (congruent and incongruent conditions), as in

the behavioral analysis. The statistical threshold was set at $p < 0.05$ (false discovery rate [FDR] corrected at the cluster level; $p < 0.001$ uncorrected at the voxel level).

In the experimental group, the two sessions activated different brain regions (see Tables 1 and 2). The transfer session showed more activation in left inferior frontal gyrus, left superior temporal gyrus, left inferior parietal lobule and left insula lobe. In contrast, the control session showed more activation in right postcentral and precentral gyri (brain pictures refer to appendix D and E). There was no interaction between session and congruency. In the control group, there was no significant difference in brain activations for the control and transfer sessions.

Table 1: Brain Areas activated in Experimental group (Transfer > Control)

| Lobe | Label | Side | x | y | z | Max t |
|------------------|--------------------------|------|-----|-----|----|-------|
| Frontal | Inferior Frontal Gyrus | Left | -48 | 14 | 8 | 4.23 |
| | | | -62 | -34 | 39 | 3.74 |
| Temporal | Superior Temporal Gyrus | Left | -48 | 0 | 0 | 3.57 |
| Frontal/temporal | Insula Lobe | Left | -36 | 10 | 6 | 4.02 |
| | Angular Gyrus | Left | -42 | -58 | 46 | 4.16 |
| Parietal | Inferior Parietal Lobule | Left | -36 | 52 | 38 | 3.37 |
| | | | -32 | -68 | 46 | 3.36 |

Table 2: Brain Areas activated for Experimental group (Control > Transfer)

| Lobe | Label | Side | x | y | z | Max t |
|----------|-------------------|-------|----|-----|----|-------|
| Parietal | Postcentral Gyrus | Right | 34 | -26 | 51 | 4.36 |
| Frontal | Precentral Gyrus | Right | 34 | -26 | 59 | 4.09 |

Behavioral data

Between group analyses: Analysis of variance (ANOVA) was used to test differences in reaction time (RT) and error rate (ER) as a function of group, session and congruency. The RT data are shown in Table 3. There was a three-way interaction between group, session and congruency $F(1,18) = 7.14, p < 0.05$. The interaction between session and congruency was of borderline significance $F(1,18) = 4.11, p = 0.058$. This shows that the magnitude of the difference between congruent and incongruent trials (the Simon effect) was greater in the transfer session than that in the control session. An interaction between congruency and group was also observed $F(1,18) = 7.68, p < 0.05$. This shows that the Simon effect in the two groups in the transfer session is different; the Simon effect was enhanced for the control group while it was reduced or even reversed for the experimental group. When comparing the mean reaction times, a Simon Effect was found in both experimental and control groups during the control session though the effect was not statistically significant $F(1,19) = 3.12, p = 0.085$. This is probably the result of a relatively small sample size.

Table 4 shows the error rates for both groups. A three-way interaction was found $F(1,18) = 6.87, p < 0.05$. There was a two-way interaction between session and group $F(1,18) = 6.30, p < 0.05$. This shows that the control group produced fewer errors in the control session compared to the other conditions.

Within-Group Analysis. For the experimental group, the Simon effect was reversed in the transfer session $F(1,9) = 6.26, p < 0.05$. Participants took longer to respond to the congruent trials than to incongruent trials. For the control group, the difference in RTs between the two sessions was not statistically significant $F(1,9) = -0.88, p = 0.37$. However, the mean reaction time difference showed that the Simon effect was

enhanced in the transfer session for the control group (i.e. difference in reaction time for congruent and incongruent trials is larger in the transfer session than in the control session).

Mixed two-way ANOVA was used to investigate the effects of both session and congruency in each group on the error rate. For the control group, the main effect of session was significant $F(1,9)=7.2, p<0.05$. Participants made more errors in the transfer session than in the control session. This may be due to fatigue given the many hundreds of trials. No interaction was found between session and congruency $F(1,9) = 1.39, p=0.28$. For the Experimental group, there was an interaction between session and congruency $F(1,9) = 5.92, p<0.05$. This shows participants in the experimental group make more errors for congruent trials in the transfer session while they made more errors for incongruent trials in the control session.

Table 3: Mean (Standard deviation) Reaction Times (in millisecond) by Group and Session

| | Control session | | Transfer session | |
|--------------------|-----------------|--------------|------------------|-------------|
| | congruent | incongruent | congruent | incongruent |
| Experimental Group | 499.0 (76.2) | 507.5 (70.8) | 490 (90.6) | 477 (80.8) |
| Control Group | 470 (56.8) | 479 (61.1) | 470 (70.1) | 482 (79.3) |

Note- For the experimental group, incompatible spatial location mapping was calculated between control and transfer sessions. For the control group, compatible spatial location mapping was calculated between control and transfer sessions.

Table 4: Mean (Standard deviation) Error Rates by Group and Session

| | | Control session | | Transfer session | |
|---------------|----|-----------------|---------------|------------------|---------------|
| | | congruent | incongruent | congruent | incongruent |
| Experimental | ER | 0.048 (0.39) | 0.050 (0.034) | 0.063 (0.047) | 0.032 (0.046) |
| Group | | | | | |
| Control Group | ER | 0.027 (0.035) | 0.033 (0.024) | 0.039 (0.052) | 0.058 (0.036) |

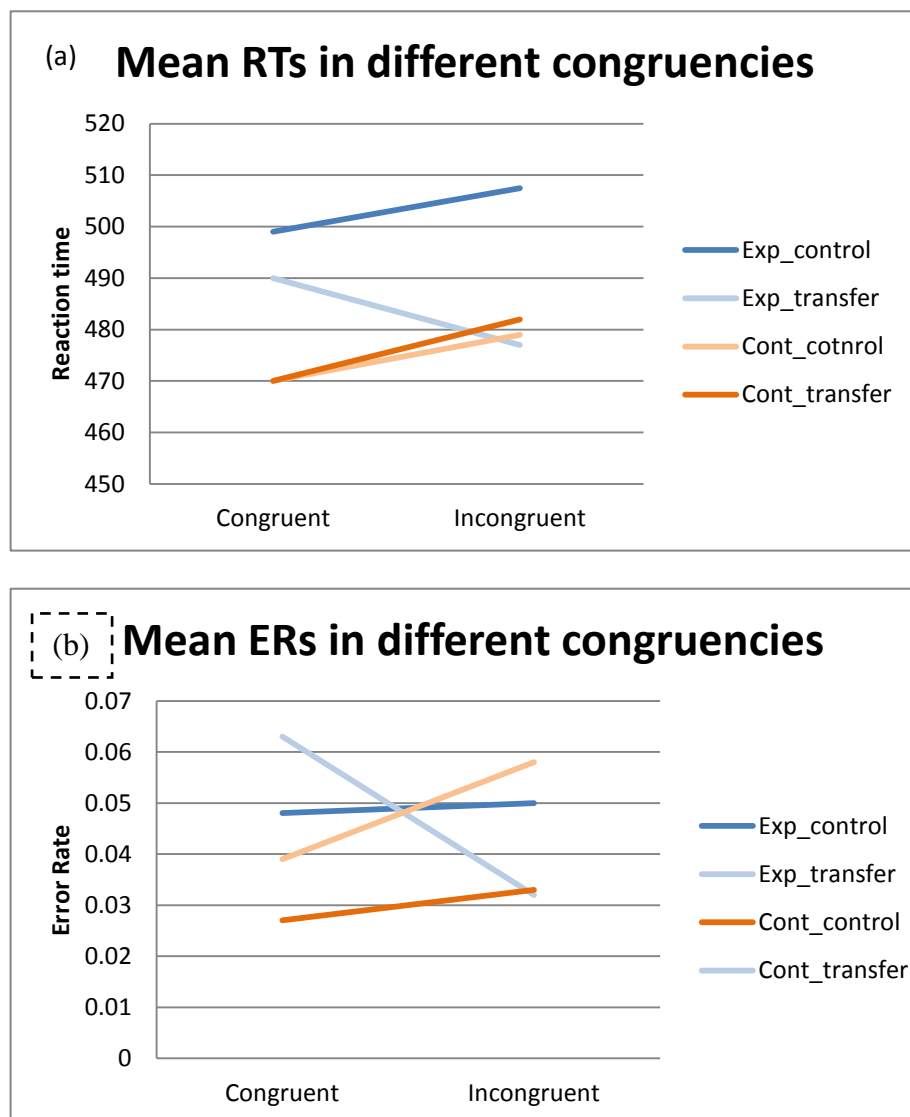


Fig. 1: (a) Mean RTs for experimental and control group in the two sessions in difference congruencies. (b) Mean ERs for experimental and control group in the two sessions in difference congruencies.

Working Memory Correlation: Individual differences in working memory scores were correlated with the magnitude of the practice effect (i.e. the difference in Simon effect across each session) in experimental group. There was medium correlation between the working memory score and the practice effect (i.e. a reduced Simon Effect in transfer session from the control session), coefficient $r = 0.384$. The positive coefficient shows that the higher the WM score, the greater the practice effect.

Discussion

The results lend some support to the main hypothesis i.e. reduced Simon effects are due to short-term-memory associations remaining active in the subsequent Simon task. It was expected that the brain regions known to be involved in working memory tasks would be more activate in the transfer sessions (following practice) than in the control sessions. In addition, it was expected that if short-term-memory associations explain reduction in the Simon effect, participants who achieve better scores in a working memory task will demonstrate a greater reduction in the Simon effect.

The results offer some support to the second hypothesis. The left inferior frontal gyrus (IFG) was more activate in the transfer session for the experimental group after the incompatible spatial location, which supports the second hypothesis. This brain region is assumed to be used for response inhibition (Swick, Ashley & Turken, 2008). Swick and colleagues reported an experiment on left IFG patients using a Go/NoGo task. It was found that the patients showed more false alarm errors (pressing the response key while they should not). However, the RTs for the false trials were faster than that of the correct trials, indicating that impulsive responding, rather than a failure to comply with task instructions can account for the increase in false alarm errors. It was concluded that left inferior frontal gyrus is responsible for inhibitory

control for motor response. However, only left IFG was more activate in the transfer session not ACC or DLPFC as expected. This may suggest that incompatible spatial location mapping increased the effort needed for response inhibitory control rather than for conflict detection. In addition, studies suggest a role for left IFG in WM tasks. Liu et al. (2004) proposed that this area may be responsible for storing information extracted from the task-relevant and task-irrelevant processing. In the present paradigm, after the spatial location mapping, a new STM link was formed (spatial location activates spatial non-corresponding response). This might interfere with LTM associations (spatial location activates the spatial corresponding response) after the STM associations are formed based on the task instructions. The information held in WM (and the inferior frontal region) was more activated in transfer sessions. The inferior frontal area is adjacent to Broca's area, which is a considered to be part of a phonological loop, particularly necessary in the articulatory rehearsal component (Smith, Jonides, Marchuetz & Koeppel, 1998). Just and Carpenter (1992) reported patients with damage to Broca's area had impaired sentence working memory spans, suggesting the inferior frontal lobe is necessary for verbal working memory, tasks supporting our hypothesis.

Left insula and superior temporal gyrus were also activated in transfer sessions compared to control. The core function of insula is to switch between neural networks to direct attention and WM resources and cooperating with the ACC to facilitate rapid access to the motor system (Tops & Boksen, 2011). Moreover, the left superior temporal gyrus is the auditory association area that is engaged during auditory STM tasks, wherein verbal materials are stored and processed (Leff et al. 2009). The activation in superior temporal gyrus in transfer session could therefore reflect the involvement of verbal WM in the Simon task. Though the location Simon task is

assumed to be a relatively non-verbal task, we know that task instructions modulate the Simon effect (Hommel, 1993). Representing spatial mappings may utilize the phonological loop, as the associations are easy to verbalize e.g. green stimulus-left press. Therefore participants may rehearse the verbal instructions in the phonological loop in favor of the execution of correct responses and this might account for the activation in inferior frontal gyrus.

Whur and Ansorge (2007) argued that the majority of participants used verbal codes instead of spatial codes for representing responses in WM as revealed by participants' self rating of performance. Hence, activation in left super temporal gyrus may be due to phonological rehearsal of task instructions in the phonological loop. Recent research conducted by Zhao, Chen and West (2010) proves the involvement of verbal STM in Simon task. In that study, the authors tried to study the contribution of spatial and verbal WM to the processing of stimulus location in the Simon Task. Participants performed a regular Simon task, followed by a dual-task. Half of the participants performed a verbal WM task while the other half performed a spatial WM task. During the dual-task, spatial or verbal WM was occupied and the magnitude of the Simon effect was compared between dual-task and regular Simon task. The Simon effect was reduced in the verbal WM task, suggesting that the coding of stimulus location in the Simon task depends on verbal WM. In addition, the findings demonstrated that stimulus-response representation in the Simon task may be represented in verbal WM, rather than in spatial WM. It appears that the Simon task requires verbal coding in working memory. Thus it is not surprising that performance activates brain areas that are necessary for language processing such as observed here. It is therefore likely that the patterns of brain activation identified in language related areas during experimental conditions above reflect the use of verbal working memory.

On the other hand, the behavioral data failed to support the predicted correlation between practice and working memory capacity. One reason may be small sample size. In addition, other factors such as loss of attention and fatigue may have reduced the practice effect. Lack of validity of the WM task may also contribute to the null results. In the WM test, mathematical calculation was involved. As performance (time used and error rate) in the mathematical component of the WM test was ignored in the scoring, the true WM capacity of the participants may not be revealed by the results.

The results showed that the inferior parietal lobule was also activated in the task. Liu et al. (2004) suggested that this brain region is responsible for passing the modulatory signal to the posterior processing areas for cognitive processing. It is also involved in the attentional resources allocation as well as facilitating processing towards the task-relevant stream so that the processing of such information is promoted. Clearly individual differences in attention should be measured on tasks that measure the effects of practice on transfer in the Simon task.

Some of brain regions showed reduced activations after practice. Postcentral and precentral gyri, the premotor and motor areas, were more activated in control session. Reduced activation after practice may suggest involvement of motor learning. Motor learning refers to a set of process associated with practice or experience giving rise to relatively permanent changes in the capacity for producing skilled action (Brauer, Woolacott & Shumway-Cook, 2001). It occurs naturally during task performance when repetitive actions are involved. The involvement of motor learning is not surprising as the Simon task involved rapid repetitive movement as the response. The movements may easily be adapted and learned in this task. The participants might have habituated the motor response so less effort was needed in the subsequent session. Van Der Lubbe and Abrahamse (2011) investigated motor involvement in

their study. They suggested a premotor theory of attention (PMTA) accounts for the Simon effect. The Simon task involves spatial representation related to both attentional selection of the visual input and the selection of an action in space. According to PMTA, these spatial representations are partially overlapped. Spatial representations involved in attentional control and response generation may overlap, so that attentional selection of the location containing the relevant stimulus primes the corresponding response, leading to the Simon effect. Several electroencephalographic (EEG) studies (e.g. Forster and Eimer, 2005; Van Velzen, Eardley, Forster and Eimer, 2006) support the claim that spatial attention and selection of spatially defined actions like eye and hand movements are closely related. An overlap of spatial representations in a shared spatial map representation may contribute to the Simon effect. According to these studies, both attending to a location stimulus and preparation of relative eye or hand movement for this same location activated the posterior parietal components. The findings in our study may be consistent with the PMTA account of the Simon effect. Though the activation in posterior parietal region was not significant in control sessions, the primary motor hand areas (precentral and postcentral gyri) were active. This is consistent with Van der Lubbe et al.'s suggestion that perception of stimuli location is related to selection of spatially defined actions like eye and hand movements. In addition, studies show that precentral gyrus is involved in response inhibition (MacLain et al. 2001; Nachev, Wydell, O'Neil, Husian & Kennard, 2007; Chen, et al, 2009). The response inhibitory centre has changed from precentral gyrus to inferior frontal gyrus. It is proposed that inferior frontal gyrus is the area for response inhibition, so in the transfer session where conflict interference increased, this area was more active than precentral gyrus.

Behavioural data.

The results show that after 300 trials of incompatible spatial location mapping, the Simon effect was reversed, as reported by Proctor et al. (2009). For the control group who underwent the compatible spatial mapping, the Simon effect was enhanced, though the increase did not reach statistical significance. These results suggest spatial mapping instructions establish short-term associations that continue to influence subsequent performance as suggested by Tagliabue et al. (2000). The present results extend these findings to Chinese speakers (Zhao, et al. 2010).

Spatial location mapping not only affected reaction time but also affected error rate. There was an interaction between session and congruency for the experimental group, such that if participants perform incompatible spatial mapping, they make more errors for congruent trials in the transfer session whereas they made more errors for incongruent trials in the control session. When comparing RT and ER graphs for the experimental groups in the two sessions, an interesting observation can be found. The incompatible mapping reduced the reaction time needed for incongruent trials while increasing the error rates for congruent trials. It could be hypothesized that the incompatible spatial location mapping enhanced links between incompatible spatial codes of the stimulus and the visuo-motor response. During the incongruent trials, mean RT reduced after the incompatible spatial location mapping task was performed. However, mean RT did not change for the congruent trials. Instead, ER of congruent trial increased. This suggests that incompatible mapping might not increase the load of response selection. Rather it induces a faster motor response before response inhibition was performed. This supports the conjecture that motor learning influences practice in the Simon task.

Clinical implication.

The results of the study help to understand how language experience can modulate

human cognitive function from a brain connectivity perspective. The study paradigm could be elaborated in future work to address questions regarding conflict processing in the brain and language learning. Such results are important for understanding how the brain changes following speech therapy and rehabilitation since cognitive control is necessary for maintaining language function not only in normal speech production but, critically, for impaired individuals including patients who are Chinese speakers.

Limitations and direction for further research.

One limitation of the current study is the small sample size. It is recommended that future research investigate neural correlates on the Simon effect with a larger number of participants. Another limitation is that only physical-location stimuli were used, not arrows or location words that are also used in investigating the Simon effect. Processing of physical-location stimuli is rather automatic, but symbolic stimuli such as arrows and location words are not (Jonides & Irwin 1981). It takes more time to respond to location words and arrows and more trials of incompatible spatial location mapping are necessary to produce reverse Simon effects compared to a physical location manipulation. Jonides and Irwin proposed that the difference in performance is likely a consequence of translation of a semantic-spatial code into a spatial code taking time for response selection. Further studies could be carried out based on the study of Proctor et al. (2009), to compare the practice effect for combinations of physical-location, arrow-direction and location-word modes in practice and transfer sessions. It could be predicted that location-word and physical-location stimulus share semantic-spatial codes with arrow but not for physical-location stimulus. Therefore, it will be meaningful to compare the brain activation using physical location, arrows and location words to investigate if different regions of brain are responsible to solve conflict for symbols or which brain region is responsible for the semantic-spatial code

translation. Finally, it would be of interest to compare neural correlates during spatial location mapping task with that of transfer in the Simon task. Neural correlates in stimulus-response compatibility task can be studied when the stimulus position is task relevant.

Conclusion

This study investigated the neural correlates of the influence of spatial location mapping using function MRI. The results showed that left inferior frontal gyrus, left superior temporal gyrus and left insula lobe were activated in transfer session after practice. In contrast, anterior cingulate cortex, pre-central gyrus and post-central gyrus were less activated after practice.

Acknowledgement

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Appendix A:*Consent Form*

言語及聽覺科學部

香港大學教育學院

五樓，菲臘牙科醫院，醫院道34號，香港西營盤

主任: 黃麗娜 博士

講座教授: Weekes, Brendan 教授

電話: 28590599/28590595, 傳真: 25590060

同意書

研究題目: “Neural correlates of the influences of spatial location mapping on the Simon effect”

尊敬的女士們，尊敬的先生們，

香港大學言語及聽覺科學部邀請您參與由莊靜敏與 Brendan Weekes 教授主理的實驗研究。

這是一項關於認知神經科學的學術研究，旨在探討人類如何加工視覺刺激的空間屬性以及如何對視覺刺激的空間屬性做出反應的神經機制。這個實驗在香港大學 3T 磁力共振掃描部進行。在實驗中，您需要完成三段基於電腦的任務，磁力共振掃描器會同時記錄您的腦部活動。在任務中，您需要按鍵對視覺刺激的顏色或空間位置做出反應。每段任務持續大約十五分鐘。此外，我們還將掃

描您大腦的結構。在正式實驗前，會有一個練習讓您來熟悉實驗所用的任務。

這個研究總體持續大約一個小時。

請您注意，如果您體內有任何金屬物體，或者您是一名正在孕期或哺乳期的女士，您將不適合參加這個磁共振實驗。在您剛填寫的磁共振掃描申請表中，我們列出了在強磁場中會對您的身體產生危害的物體。請再一次確認您的身體中不存在表中列出的物體，這對我們進行一個安全的磁共振實驗非常重要。在磁力共振掃描器工作過程中，它會發出響聲。因此，您會帶上耳塞和頭戴式耳機，以此來減少機器響聲對您的影響。請注意，在實驗進行中，如果您感覺到任何不適並且想停止這個實驗，您可以使用機器附帶的緊急設備來通知實驗者。我們會立即停止機器的掃描並幫您從磁力掃描器中脫離。

實驗結束後，您會得到 150 港元做為您參與實驗的報酬。此外，您還會得到一張您大腦的圖片。

是次參與純屬自願性質，您可隨時終止參與是項行動，有關決定將不會引致任何不良後果。所收集的資料只作研究用途，個人資料將絕對保密。在測量和存儲資料時，我們會使用一個編號而不是您的名字來存儲您的資料。有關您的研究資料會以電子資訊的方式在我們實驗室存放十年。在這之後，我們會銷毀有關您的所有研究資料。如您對是項研究有任何問題，請現在提出。

問題和疑慮

如日後你對是項研究有任何查詢，請與王凌博士 (804 房間，明華樓，香港大學；電話號碼: 2241-5980；電郵地址: lingwang@hku.hk)和 Brendan Weekes 教授(808 房間，明華樓，香港大學；電話號碼: 2241-5986；電郵地址: weekes@hku.hk)

聯絡。如你想知道更多有關研究參與者的權益，請聯絡香港大學非臨床研究操守委員會 (2241-5267)。

如你明白以上內容，並願意參與是項研究，請在下方簽署。

姓名：_____

日期：_____

Date of Preparation:

HRECNCf Approval Expiration date: 2013年5月8日

Appendix B

Questionnaire of language exposure

語言背景問卷 Questionnaire of Language Exposure

填寫問卷後，請發郵件到: h0807358@hku.hk

姓名: _____ 出生日期: _____ 性別: _____

電話: _____

您的母語(L1)是: 廣東話/ 普通話/ 英文/ 其他 (請註明)-

您第二常用的語言 (L2)是: 廣東話/ 普通話/ 英文/ 其他 (請註明)-

您所讀的高中,是以 那種語言授課的? 廣東話/ 普通話/ 英文/ 其他 (請註明)-

請填寫您平均每天使用以上兩種語言所用的時間。

| 日常活動 | | L1 | L2 |
|------|------------|----|----|
| 1 | 電視 | | |
| 2 | 收音機/ 音樂 | | |
| 3 | 家庭 | | |
| 4 | 課程 | | |
| 5 | 同學 | | |
| 6 | 朋友 (不包括同學) | | |
| 7 | 男/女朋友 | | |
| 8 | 興趣活動 | | |
| 9 | 閱讀 | | |
| 10 | 寫作 | | |

Appendix C:*Questionnaire for Handedness***Edinburgh Handedness Inventory**

Name:

Date of Birth:

Sex:

Please indicate your preferences in the use of hands in the following activities by putting ‘+’ in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ‘++’. If in any case you are really indifferent put ‘+’ in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

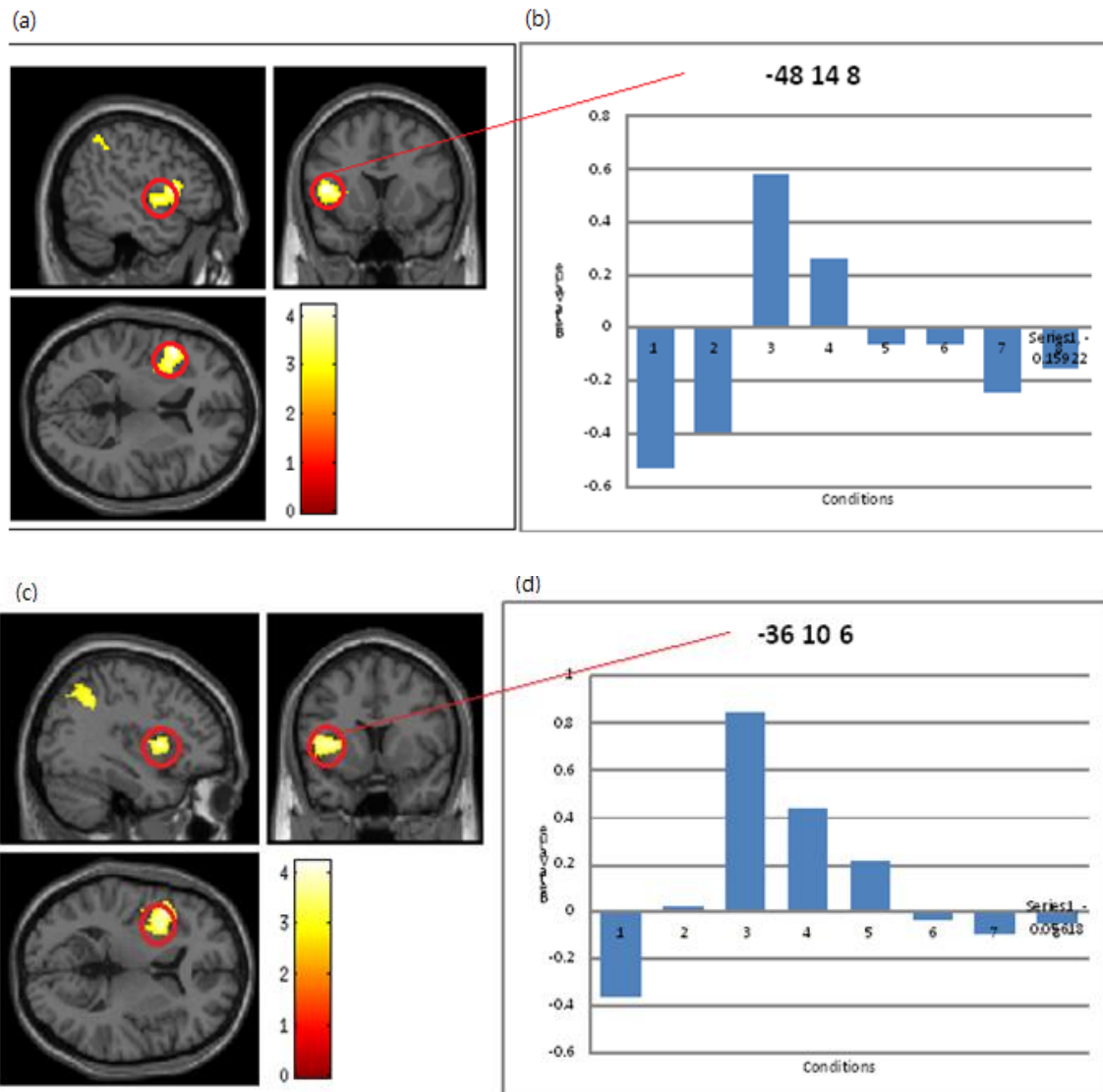
| Task / Object | | Left Hand | Right Hand |
|---------------|---|-----------|------------|
| 1 | Writing | | |
| 2 | Drawing | | |
| 3 | Throwing | | |
| 4 | Scissors | | |
| 5 | Toothbrush | | |
| 6 | Knife (without fork) | | |
| 7 | Spoon | | |
| 8 | Broom (upper hand) | | |
| 9 | Striking Match (match) | | |
| 10 | Opening a Box (lid) | | |
| I | Which foot do you prefer to kick with? | | |
| II | Which eye do you use when using only one? | | |

| | | |
|--|----------------------|------|
| Total plus signs: | LH = | RH = |
| Cumulative Total | CT = LH + RH = | |
| Difference | D = RH - LH = | |
| Result | R = (D / CT) × 100 = | |
| Interpretation: (Left Handed: $R < -40$); (Ambidextrous: $-40 \leq R \leq +40$) (Right Handed: $R > +40$) | | |

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97-113.

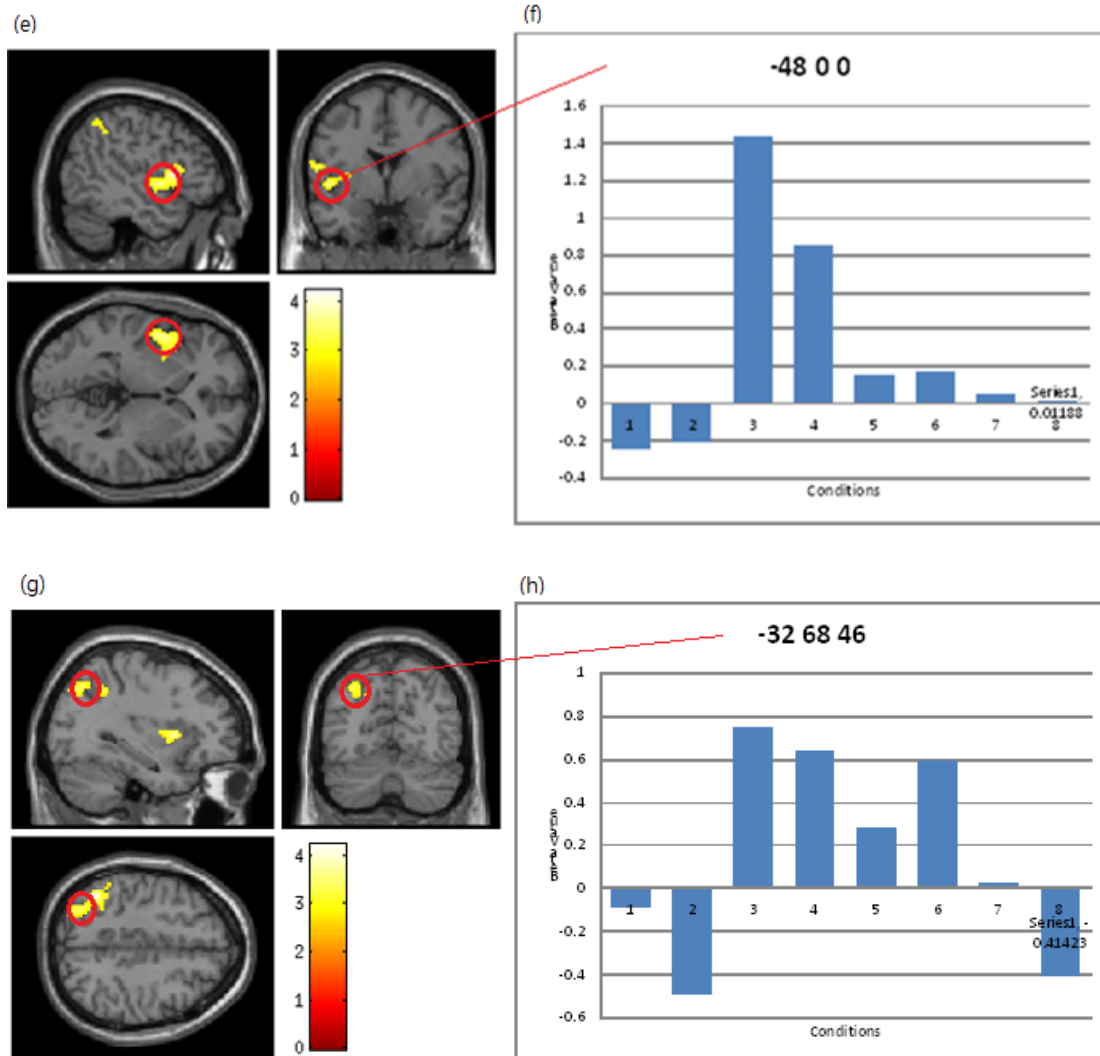
Appendix D:

Brain pictures of activation and charts of corresponding beta values in experimental group (transfer > control)



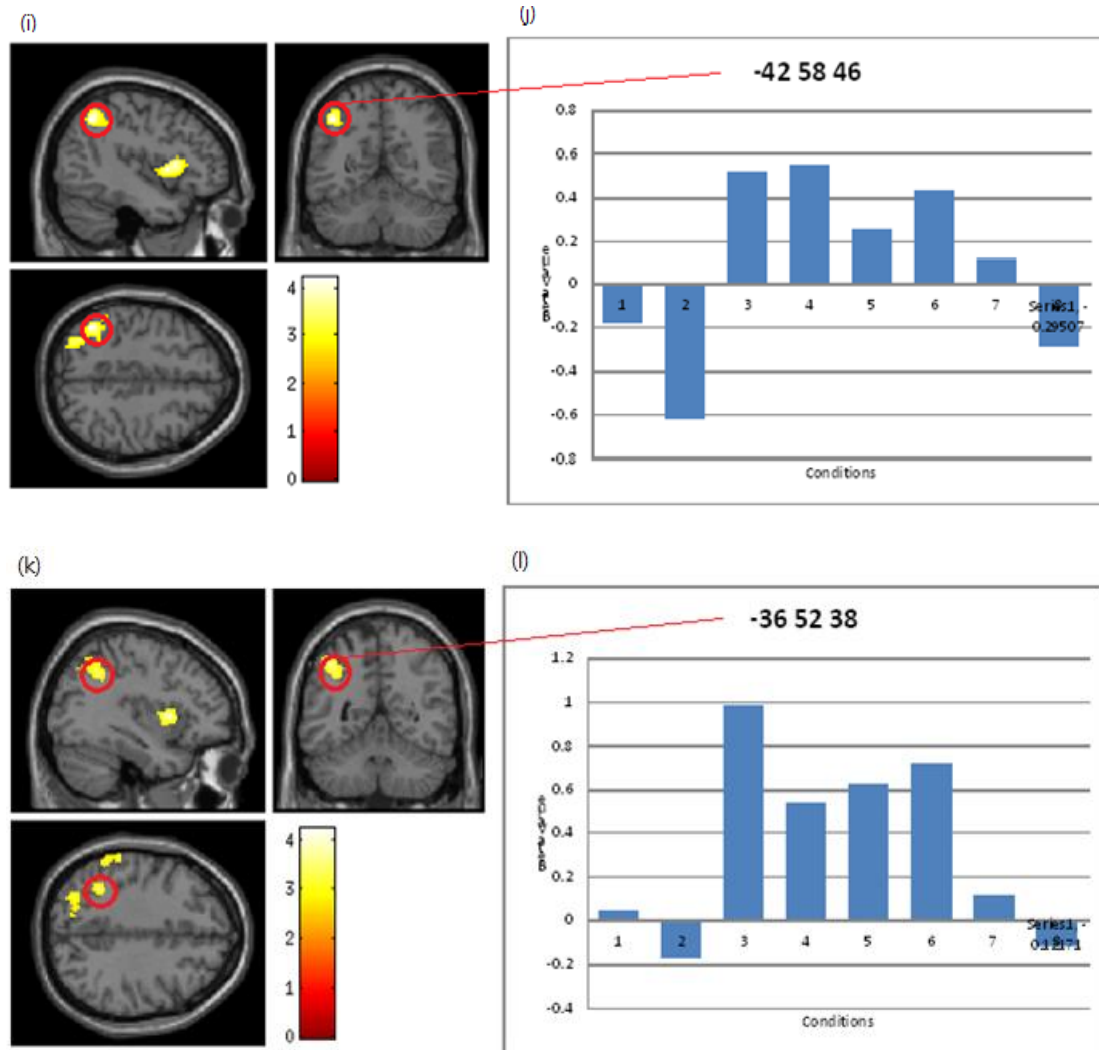
Imaging results in experimental group (Transfer > Control). (a) Left inferior frontal gyrus activation (b) beta value of the activation in left inferior frontal gyrus (c) Left insula Lobe activation (d) beta value of the activation in Left insula lobe activation

Appendix D (Cont.)



Imaging results in experimental group (Transfer > Control). (e) Left superior temporal gyrus activation (f) beta value of the activation in left superior temporal gyrus (g) Left inferior parietal lobule activation (h) beta value of the activation in left inferior parietal lobule

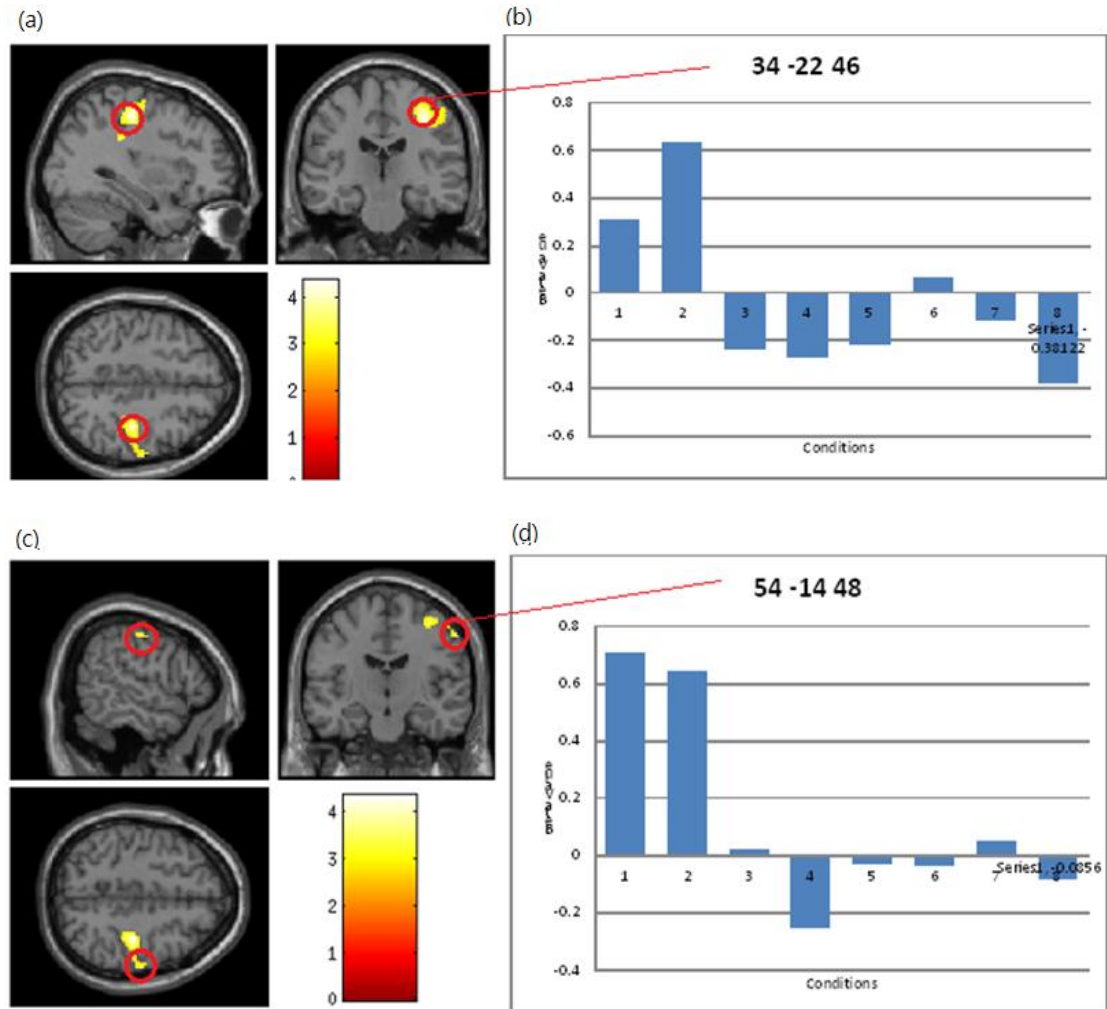
Appendix D (Cont.)



Imaging results in experimental group (Transfer > Control). (i) Left angular gyrus activation (j) beta value of the activation in left angular gyrus (k) Left inferior parietal lobule activation (l) beta value of the activation in Left inferior parietal lobule activation

Appendix E:

Brain pictures of activation and charts of corresponding beta values in experimental group (control > transfer)



Imaging results in experimental group (Control > Transfer). (a) Right postcentral gyrus activation (b) beta value of the activation in right postcentral gyrus (c) Right precentral gyrus activation (d) beta value of the activation in right precentral gyrus